X-621-71-105
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NASA TM X- 65531

OBSERVATIONS OF THERMOSPHERIC ION COMPOSITION ABOVE WALLOPS ISLAND DURING THE MARCH 7, 1970 SOLAR ECLIPSE

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MARCH 1971

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GREENBELT, MARYLAND

To be presented at the Fifty-Second Annual Meeting of the American Geophysical Union April 12, 1971, Sheraton-Park Hotel, Washington, D. C.

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INTRODUCTION

On March 7, 1970 a total eclipse of the sun occurred over the eastern portion of the North American continent. Two thermosphere probe positive ion mass spectrometers, launched 38 and 11 minutes before totality from Wallops Island, measured the ion composition in the F-region from 130 to 290 kilometers altitude. These measurements were part of the coordinated experiment, sponsored jointly by NASA's Goddard Space Flight Center and the University of Michigan, to investigate the thermal balance, photochemistry, and dynamic response of the charged and neutral constituents to changing solar conditions. The electrostatic probes of L. H. Brace (NASA/GSFC) measured the electron temperature and density, while the omegatron mass spectrometers of N. W. Spencer (NASA/GSFC) and G. R. Carignan (Univ. of Mich.) measured the N_2 temperature and density on these flights. As shown in Figure 1, Nike-Tomahawk sounding rockets NASA 18.104 and 18.105, launched at 1300 EST and 1327 EST respectively, carried the two identically instrumented thermosphere probes along nearly the same trajectories into the eclipse path.

In this report we present the first measurement results of the ion spectrometer and compare them briefly with Stubbe's (1970) theoretical predictions of the ion composition at totality during the eclipse. More complete reports now in process, treat the combined results of the thermosphere probes and give extensive interpretation of the eclipse ionosphere F-region dynamics.

INSTRUMENTATION

The cylindrical thermosphere probe, about 7 inches in diameter and 40 inches in length, was sealed to prevent the outgassing of contaminants during the flight. On ascent, at approximately 71 kilometers altitude, a spring-plunger mechanism ejected the thermosphere probe from the protective clamshell nosecone of the rocket. A tension lanyard attached between a negator motor in the clamshell and the probe imparted a prescribed tumbling motion to the instrument during ejection. The complete details of the thermosphere probe experiment technique have been described by Spencer et al. (1965).

The operation of Bennett ion mass spectrometers has been described in detail by Johnson (1960) and Taylor et al. (1963, 1965). In this paper only the specifications unique to the eclipse instruments are described. Similar thermosphere probe ion mass spectrometers were flown on August 26, 1966 (Pharo et al., 1971) from Wallops Island and on March 17, 1968 from Mar Chiquita, Puerto Rico. Figure 2 shows the 12 inch long ion spectrometer section of the payload. The sensor, a 7-5 cycle ceramic Bennett tube with a grid spacing of 3 millimeters, was mounted coaxially with the orifice located in the end of the instrument. The analyzer RF was 5.4 MHz. The accelerating voltage swept the ion mass range from 12 to 36 AMU in approximately 0.2 seconds. By switching the stopping voltage at the end of each sweep, two different sensitivities were achieved. A commutated analog telemetry channel monitored the spectrometer housekeeping functions, which included the stopping voltage, RF voltage, and other sensor-grid voltages. Each ion spectrometer contained both a decade analog data system and a digital (peak-detector) data system, which covered the ion-current range of 2×10^{-12} to 5×10^{-9} amperes. The analog data system utilized four telemetry channels, three for the decade amplifier outputs of the ion peak amplitudes, and an additional channel for the accelerating voltage sweep, which is used to identify the mass of the ion peaks. The digital data systems combined the same ion peak information into a single channel output consisting of two 8-bit words, one for the accelerating voltage sweep and the other for the ion peak amplitude. The digital data system readout occurred at a fixed rate. To prevent loss of ion peak information, between the time of ion peak recognition (by the peak-detector) and the time the readout occurred, the accelerating voltage sweep was stopped until the digital data readout was completed. This resulted in accelerating voltage sweeps which differed slightly in time duration, depending upon the number of ion peaks detected during the sweep.

DATA REDUCTION AND ANALYSIS

Approximately 2100 ion spectra were obtained on each flight from 100 kilometers altitude during ascent, through peak altitude (290 kilometers) to 90 kilometers on descent. The descent data were chosen for complete analysis, since the ion spectrometer angles with respect to the velocity vector were considerably smaller during descent. The NASA 18.104 and 18.105 thermosphere probes tumbled with periods of 11.16 seconds and 2.45 seconds respectively, producing a cyclic modulation of the ion currents measured. Aspect information was obtained from solar-aspect sensors mounted on each instrument package. Good aspect data were obtained from the first flight; however, ambiguities in the aspect data from the second flight required the use of ion spectrometer data to provide a unique determination. Fortunately, the earth-sun line and the plane of the thermosphere probe tumble were frequently coincident on the later flight. This resulted in solar illumination of the ion spectrometer collector during a small portion of each tumble cycle, producing a pronounced symmetrical variation in the spectrometer output during the period of collector illumination. While the solar illumination compromised small portions of the ion data during each tumble on NASA 18.105, enough good data were obtained to provide adequate altitude resolution.

Nearly 7 minutes of analog and digital experiment data were telemetered during each flight. A series of computer programs was written to process the large volume of data. The first step in the processing was to digitize the ground station tapes. An analysis program then decoded the 8-bit accelerating voltage sweep and ion peak amplitude digital experiment words. The next program produced the constituent ion currents from the experiment digital data by incorporating mass discrimination and instrument calibration factors determined in laboratory tests. The analog data served as a basis for calculating the in-flight calibration factors needed by the computer in the two previous steps. The computer then merged the ion current data with the trajectory data and produced plots of ion current versus altitude and versus time. These profiles were then smoothed, and each ion current I_n was converted to a corresponding ion concentration N_n by normalizing to the total ion concentration N_i. The conversion equation is

$$N_n = I_n \times \frac{N_i}{\Sigma I_n}$$

$$n = 1 \text{ to } N$$

where N is the total number of ion constituents measured at a given altitude. Figures 3 and 4 show the resulting descent ion concentration profiles between peak altitude and 130 kilometers. By assuming $N_i = N_e$, the N_i profile was derived from measurements of N_e taken during the flights by the ground-based ionosonde at Wallops Island, reported by Jackson and McQuillan (1970), and from data obtained by the electrostatic probes of L. H. Brace, flown on the same thermosphere probes as the ion spectrometers. Below 135 kilometers, where uncertainties in the ionosonde results exist, the electrostatic probe results were used exclusively. Analysis of the ion composition data below 130 kilometers is more complex due to the apparent presence of structured layers. Analysis of these data is in process.

COMPARISON OF THE RESULTS

The ion concentration of N^+, O^+, N_2^+, NO^+, and O_2^+ and the total ion concentration, N_i, measured at 1304 EST (NASA 18.104) and 1331 EST (NASA 18.105) are compared in Figure 5. The results were obtained prior to totality during the descent portion of the two flights as the solar obscuration changed from 42 percent to 84 percent at 290 kilometers and from 50 percent to 92 percent at 130 kilometers on the respective flights. All detected ion species decreased in concentration throughout the altitude range from the first to the second measurement. The greatest reductions occurred in the lower F-region. The reduction in the total ion concentration between the time of the later flight and totality was measured by the Wallops Island ionosonde. Jackson and McQuillan (1970) have shown this decrease to be no larger than a factor of 2 over the altitude range of the ion spectrometer measurements.

The dominant ion constituent in the F-region during both flights was O^+, which exceeded both NO^+ and $O_2{}^+$ above 165 kilometers on NASA 18.104 and above 175 kilometers on NASA 18.105. The concentration of N^+ became greater than NO^+ and $O_2{}^+$ above 250 kilometers and 260 kilometers on the respective flights. The molecular ions, NO^+ and $O_2{}^+$ exhibited the same type of smooth parallel altitude distributions that were observed by Pharo et al. (1971) in the NASA 18.06 results. The reduction in $N_2{}^+$ concentration is uncertain, but at least a factor of 2 between the flights can be assumed over the entire altitude range since $N_2{}^+$ exceeded the spectrometer limiting sensitivity on the first flight by only a factor of 2 and was absent entirely on the second flight.

Stubbe (1970) has described a method of solving the coupled system of continuity equations and applied them to simulate the effect of a total eclipse in the ionosphere. Figure 6 shows Stubbe's prediction of the ion composition at totality for the March 7, 1970 solar eclipse at Wallops Island, Virginia, derived nearly 2 years before the eclipse and, for comparison, the ion composition measured by the NASA 18.105 thermosphere probe ion mass spectrometer. The differences between our measurements and Stubbe's predictions are rather significant. The greatest differences occur in the O^+ distribution. Stubbe has predicted the crossover altitude, where O^+ exceeds NO^+ and O_2^+, to be approximately 225 kilometers, 50 kilometers above the measured crossover altitude. In addition, the measured O^+ concentration exceeds Stubbe's by approximately a factor of 5 at 290 kilometers, with the difference increasing toward lower altitudes. The prediction shows O_2^+ greater than NO^+ above the O^+ crossover, which is not consistent with the measured profiles; also the NO^+ and O_2^+ concentrations are more than a factor of 3 higher than measured. It is quite clear (Figure 6) that the differences between the measured and predicted composition are significant in all of the ions; however, similar differences exist between Stubbe's 1340 EST normal ionosphere and the NASA 18.104 ion composition, obtained 38 minutes before totality. It would be instructive to recalculate the Stubbe model for both the non eclipse and eclipse cases considering the thermosphere probe results.

DISCUSSION

These two measurements of the eclipse ion composition in the F-region have established the decay gradients needed to model a time dependent ionosphere. While no new results pertaining to the photochemistry are presented in this paper, research is being conducted in cooperation with the other members of the thermosphere probe science team which will incorporate the results of companion N_2 and electron experiments. These measurements are being used in the ionosphere model of Dr. H. G. Mayr which was successfully used with the ion composition data from NASA 18.06 (Pharo et al., 1971), and the results will be presented at the special eclipse symposium to be held at COSPAR in Seattle, Washington in June of this year.

The ion composition predictions of Stubbe made prior to the eclipse were for totality at a single geographic location, conditions not satisfied by the rocket trajectories of the thermosphere probes. In part, this may account for some of the differences in the measured and predicted ion composition. By adjusting the Mayr model to account for the variation in solar obscuration along the rocket trajectories. it will be possible to do a more complete analysis of the eclipse ion spectrometer measurements.

ACKNOWLEDGMENTS

The authors wish to acknowledge their indebtedness to the following individuals and their co-workers at Goddard Space Flight Center, University of Michigan, and Aero Geo Astro Corporation, whose participation in the design, development, and calibration of the experiment instrumentation ensured a successful mission: J. S. Burcham (GSFC); G. R. Carignan, H. I. Grassi, and J. Maurer (Univ. of Mich.); J. T. Coulson, L. T. Fry, P. K. Monaghan, D. E. Simons, and Dr. T. C. G. Wagner (AGAC).

The authors are especially indebted to B. Karmilowicz, L. Kalinowski, and P. Hinds of the GSFC Sounding Rocket Division - Instrumentation Branch telemetry ground station for their outstanding support in acquiring, digitizing, and processing the ion mass spectrometer flight records.

The authors wish to thank Dr. H. G. Mayr (GSFC) for helpful discussions in the analysis of the data and L. H. Brace (GSFC) for the use of the electrostatic probe results.

REFERENCES

Jackson, J. E. and McQuillan, C. J. (1970). The behavior of the ionosphere above Wallops Island during the eclipse of 7 March 1970. NASA Goddard Space Flight Center Rept. X-625-70-394.

Johnson, C. Y. (1960). Bennett radio frequency spectrometer. The Encyclopedia of Spectroscopy, ed. George L. Clark, Reinhold Publ. Co., New York.

Pharo, M. W., III, Scott, L. R., Mayr, H. G., Brace, L. H., and Taylor, H. A., Jr. (1971). An experimental study of the ion chemistry and thermal balance in the E- and F-regions above Wallops Island. Planet. Space Sci., 19, 15.

Spencer, N. W., Brace, L. H., Carignan, G. R., Taeusch, D. R., and Niemann, H. B. (1965). Electron and molecular nitrogen temperature and density in the thermosphere. J. Geophys. Res. 70, 2665.

Stubbe, P. (1970). The F-region during an eclipse - a theoretical study. J. Atmos. Terr. Phys. 32, 1109.

Taylor, H. A., Jr., Brace, L. H., Brinton, H. C., and Smith, C. R. (1963). Direct measurements of helium and hydrogen ion concentration and total ion density to an altitude of 940 km. J. Geophys. Res. 68, 5339.

Taylor, H. A., Jr., Brinton, H. C. and Smith, C. R. (1965). Positive ion composition in the magnetoionosphere obtained from the OGO-A satellite. J. Geophys. Res. 70, 5769.

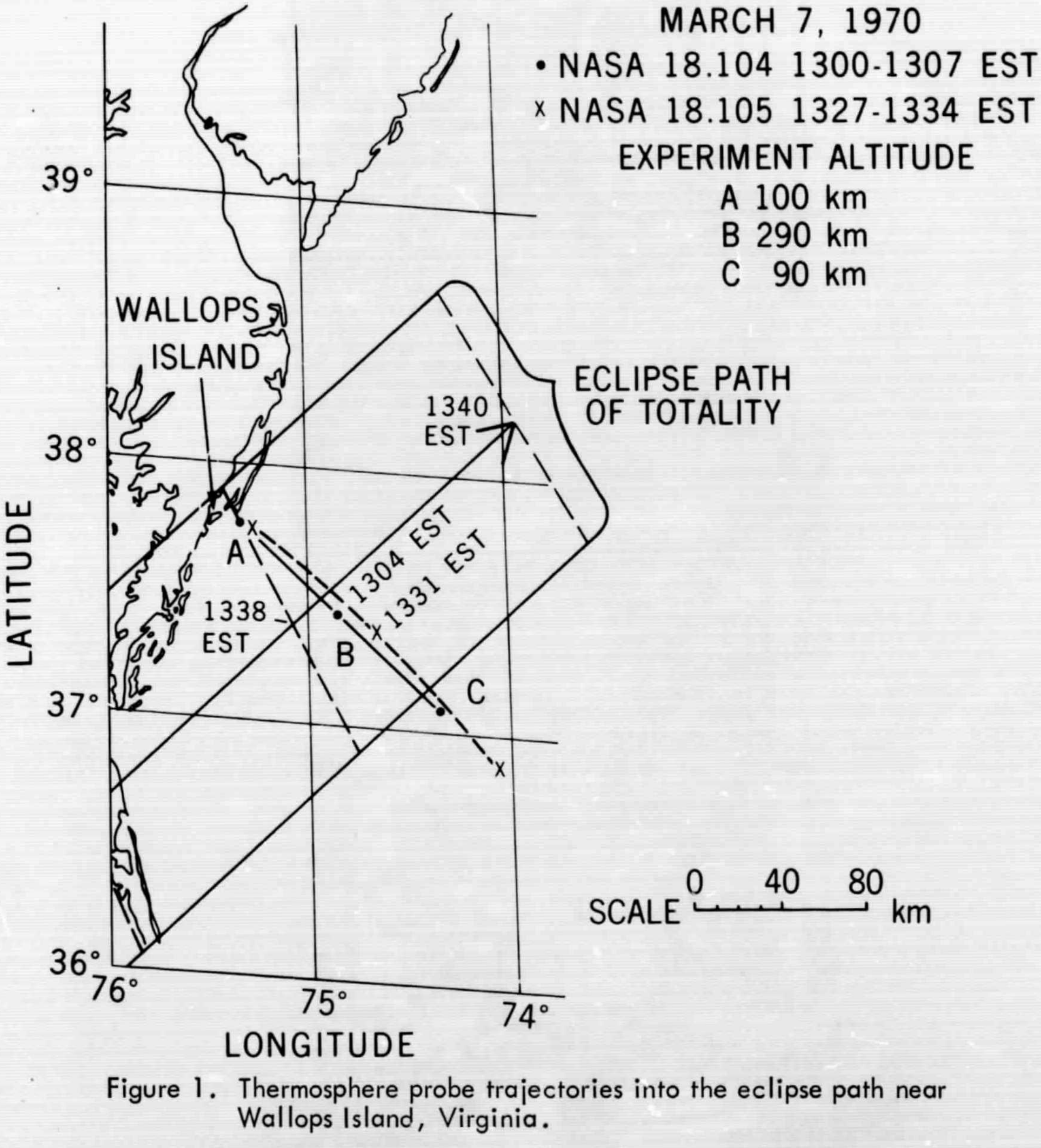

Figure 1. Thermosphere probe trajectories into the eclipse path near Wallops Island, Virginia.

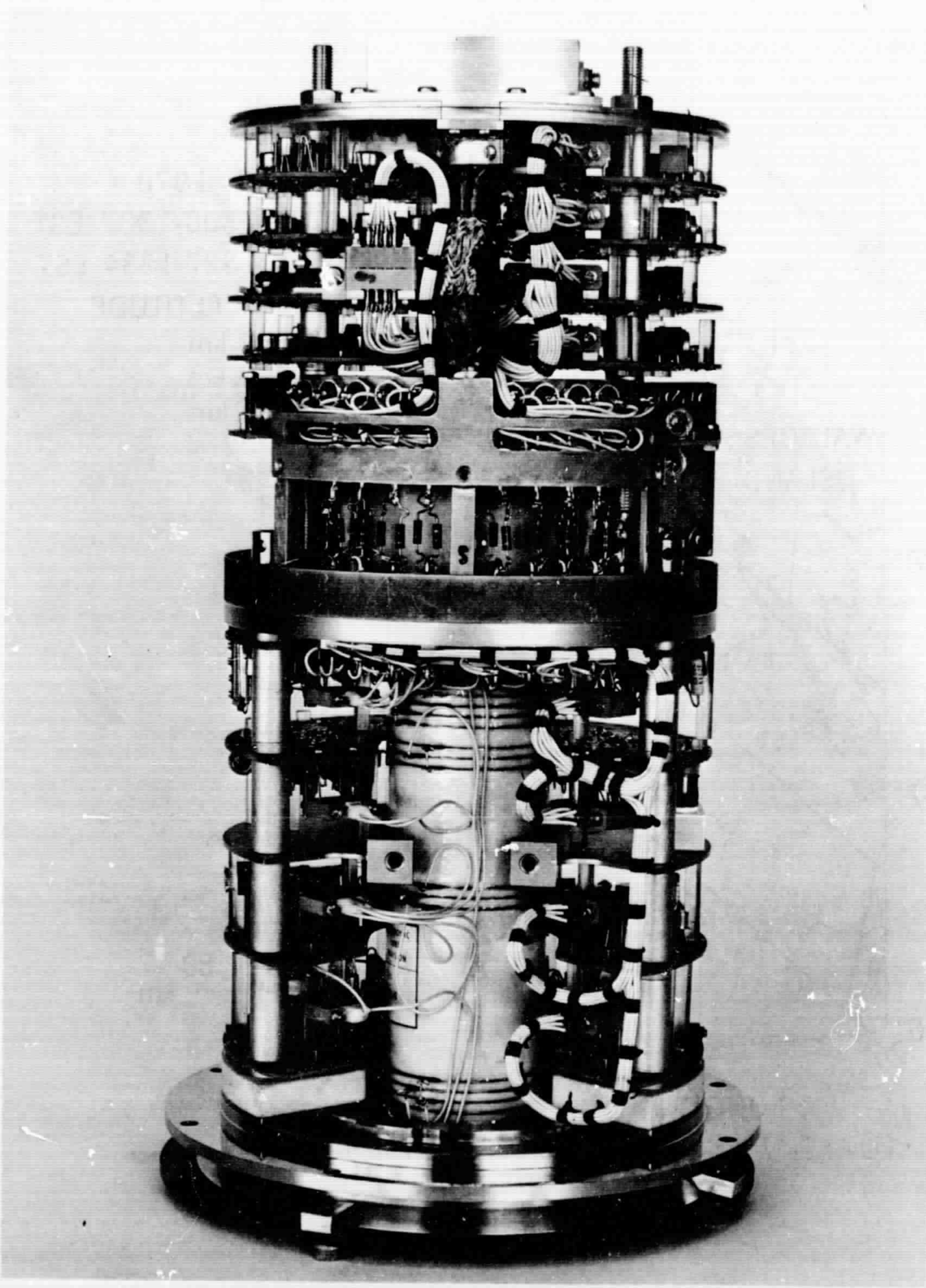

Figure 2. Thermosphere probe Bennett positive ion mass spectrometer instrument.

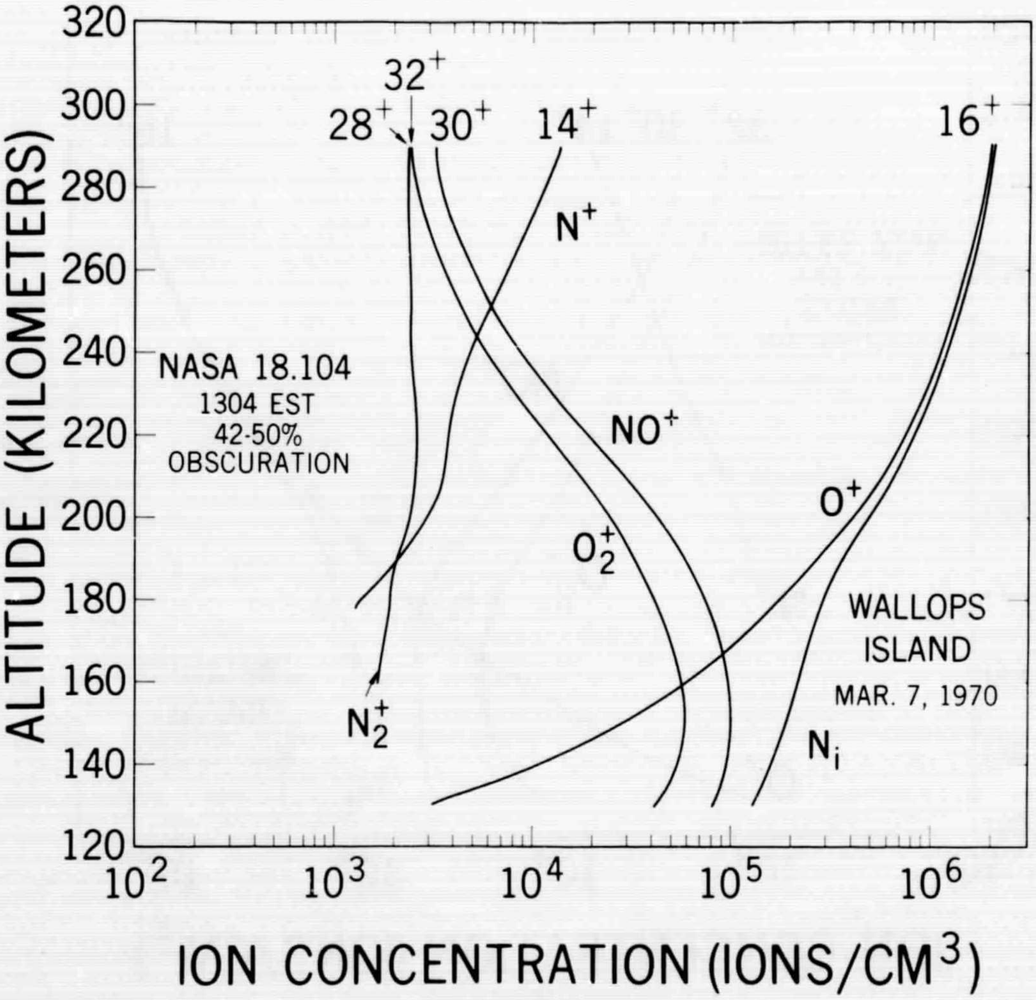

Figure 3. Ion concentration profiles measured by the Bennett positive ion mass spectrometer on NASA 18.104, from 42–50 percent solar obscuration at 290 and 130 kilometers, respectively, during the descent portion of the trajectory.

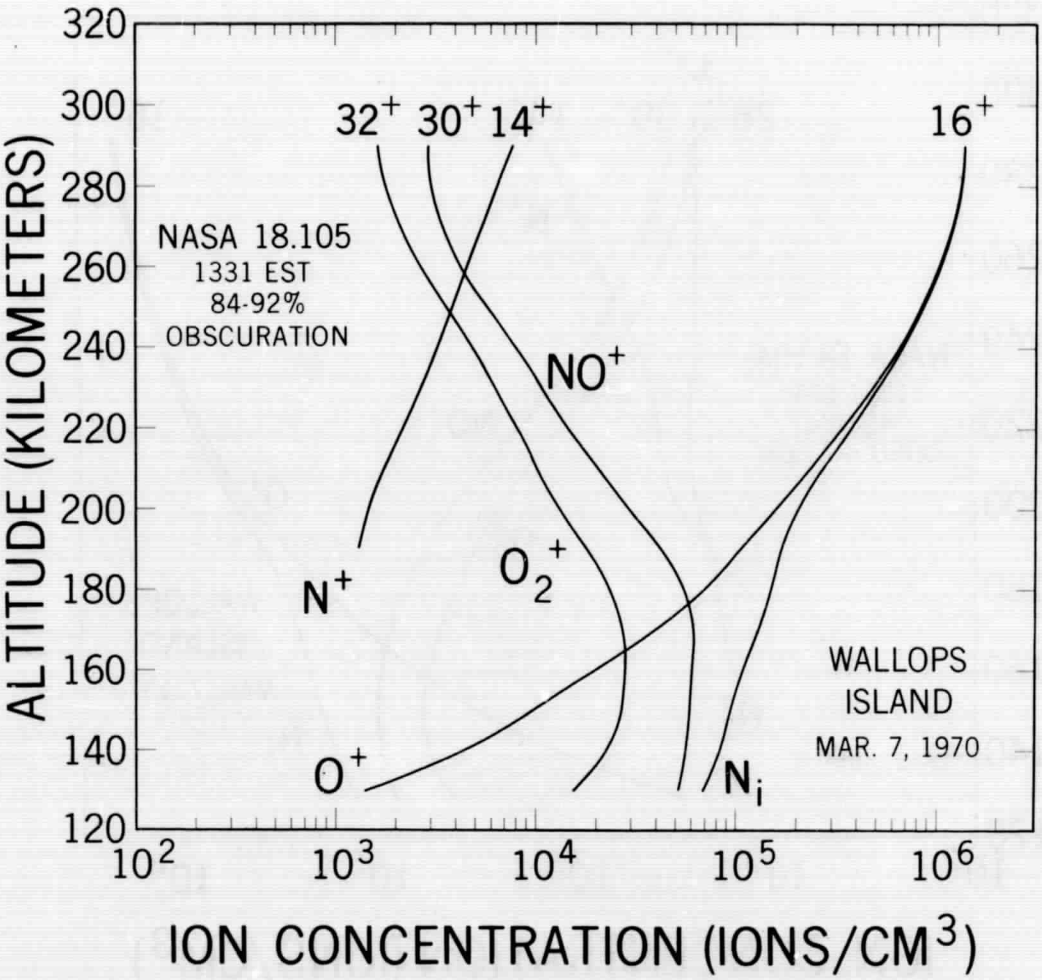

Figure 4. Ion concentration profiles measured by the Bennett positive ion mass spectrometer on NASA 18.105, from 84-92 percent solar obscuration at 290 and 130 kilometers, respectively, during the descent portion of the trajectory.

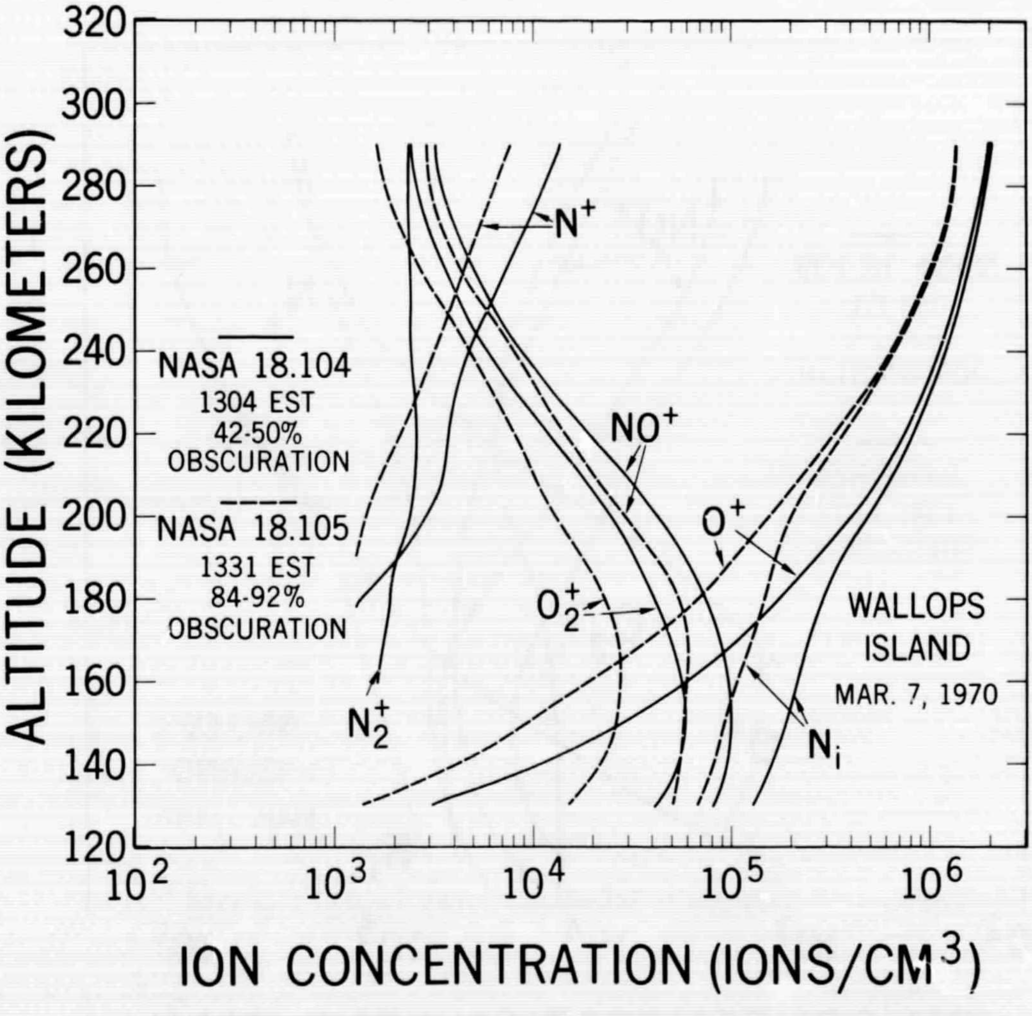

Figure 5. Ion concentration profiles measured above Wallops Island during the March 7, 1970 solar eclipse by Bennett positive ion mass spectrometers flown on thermosphere probes NASA 18.104 and 18.105, 38 and 11 minutes before totality.

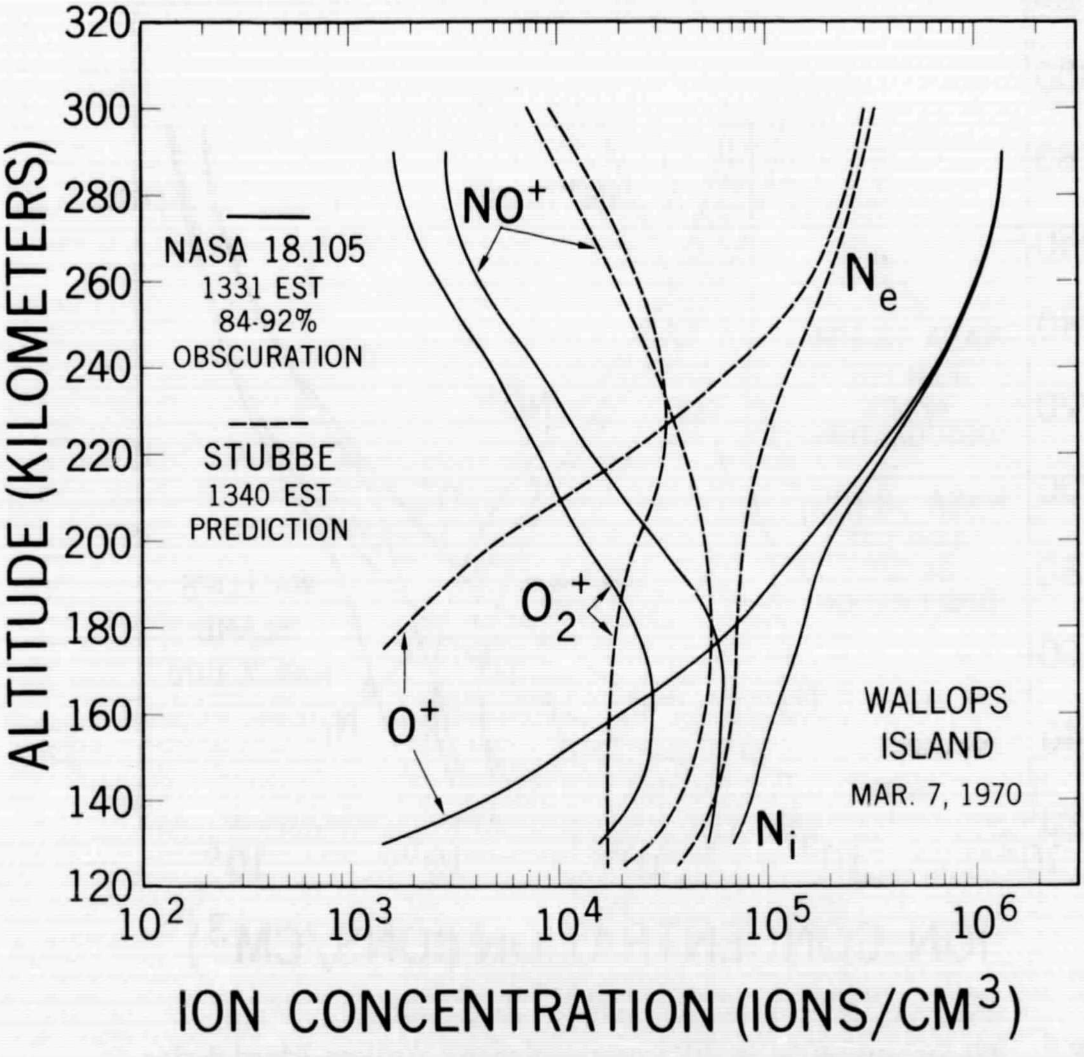

Figure 6. Comparison of measured and predicted ion composition near totality at Wallops Island for the March 7, 1970 solar eclipse.